national accelerator laboratory

ACCELERATOR EXPERIMENT--Development of Tune Spread During
                    Acceleration in the Main Ring

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1. General

The main ring is known to contain large remanent fields of
sextupole configuration. Uncorrected, the zero azimuthal Fourier
component of sextupole is sufficient to produce a chromaticity:

$$p\frac{d\nu}{dp} \stackrel{\sim}{=} 180$$

so that an injected beam, having a momentum spread of
$\pm 0 \cdot 8 \times 10^{-3}$, would contain protons whose tune varied over a
spread:

$$\Delta\nu = 0 \cdot 3.$$

The air cored sextupoles which have been used since the
early days to correct this chromaticity do not afford independent
control of $\frac{d\nu}{dp}x$ and $\frac{d\nu}{dp}y$. The machine seems to work best with them
set to cancel the momentum dependence of νy, leaving a νx
dependence:

$$p\frac{d\nu_x}{dp} = 20.$$

It is to be expected that, as acceleration proceeds, eddy
current fields in the vacuum chamber will add to this residual
chromaticity. This will cause the tune spread to grow. Moreover,
measurements of the development of the momentum spread confirm
the prediction that $\Delta p/p$ swells to about twice its injection value
on passing transition. Both the effect of eddy currents, which
varies as $\dot{B}/B$, and the momentum swelling occur between 8 and 30

GeV. This is just where quadrupole tuning is found to be most critical.

A previous experiment (EXP-41) had shown the existence of wide stop bands at injection and even at 27 GeV. The beam must be steered through these during acceleration. It was therefore important to measure the development of the tune spread in the beam up to 50 GeV in order to determine whether emphasis should be placed on correction of chromaticity to reduce the area of the tune diagram occupied by the beam in addition to efforts to compensate stop bands which would leave more clear space between them.

2. Techniques

The experiment was performed after the machine had been tuned by the operators for reasonably stable operation at 300 GeV. Conditions can therefore be assumed to be representative of normal operation. A single booster batch was used for the study. Sextupoles were set to correct chromaticity and to roughly compensate the 61st harmonic. Octupoles and the tune-splitter were off.

As in EXP-41, a pinger was used to excite radial and vertical coherent betatron motion. The amplitudes of these oscillations at injection were 3 and 5 mm respectively. The pinger and the oscilloscope used to view the oscillations were triggered simultaneously at various points in the cycle from 8 to 50 GeV. Dipole current was used to monitor energy.

Fig. 1 shows a typical photograph of a trace. The coherent motion damps to half its initial amplitude in n turns. The reason for the damping is that protons of different momenta have different tunes and get out of phase.

Consider two protons at the edges of the distribution of momentum or tune. Suppose their tune difference is $\Delta\nu$. After n turns, their motion becomes out of phase by $2\pi n \Delta\nu$. It is not difficult to see qualitatively that if this phase lag is as much

as 2π so that

$$\Delta\nu = \frac{1}{n} \quad \ldots \ldots (1)$$

then the coherent motion of the bulk of the protons near the centre of the distribution will have damped to about half of the initial amplitude.

Exact Fourier transform treatment shows that if the momentum distribution is Gaussian, the tune spread given by (1) corresponds to that between two protons separated by 2·3 times the width at half height of the distribution. $\Delta\nu$ therefore contains over 97% of the beam.

Fig. 2 shows how the tune spread, $\Delta\nu$, develops in radial and vertical planes. The shape of the curve has all the qualitative features of predictions of the combined effects of remanent and eddy current sextupole plus the swelling of Δp at transition. The latter is manifested by the sharp peak at 17·5 GeV.

The mean tune was also obtained from each of the photographs. Fig. 3 shows its variation during the cycle together with the spread at the edges, $\Delta\nu$. Clearly the fringes of the momentum distribution hit and even cross stop bands.

3.   Conclusions

The tune spread due to momentum spread is only fully compensated in the vertical plane and at injection. It is serious enough to explain losses in the parabola and the observed sensitivity of the main ring to the quadrupole programme in that region. While it will still be necessary to compensate the wide stop bands at injection, independent and ramped control of chromaticity is of equal importance and should be attempted first to make resonance exploration cleaner.
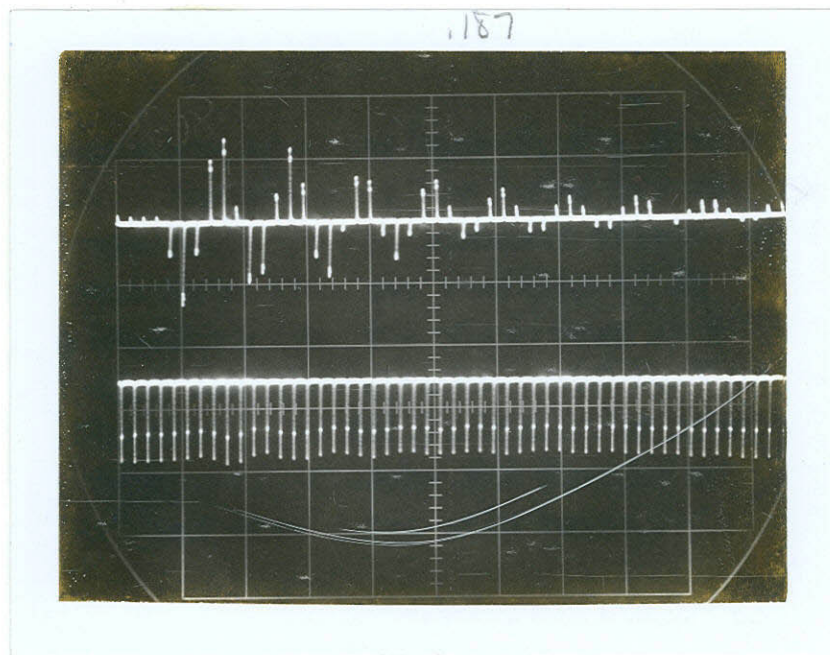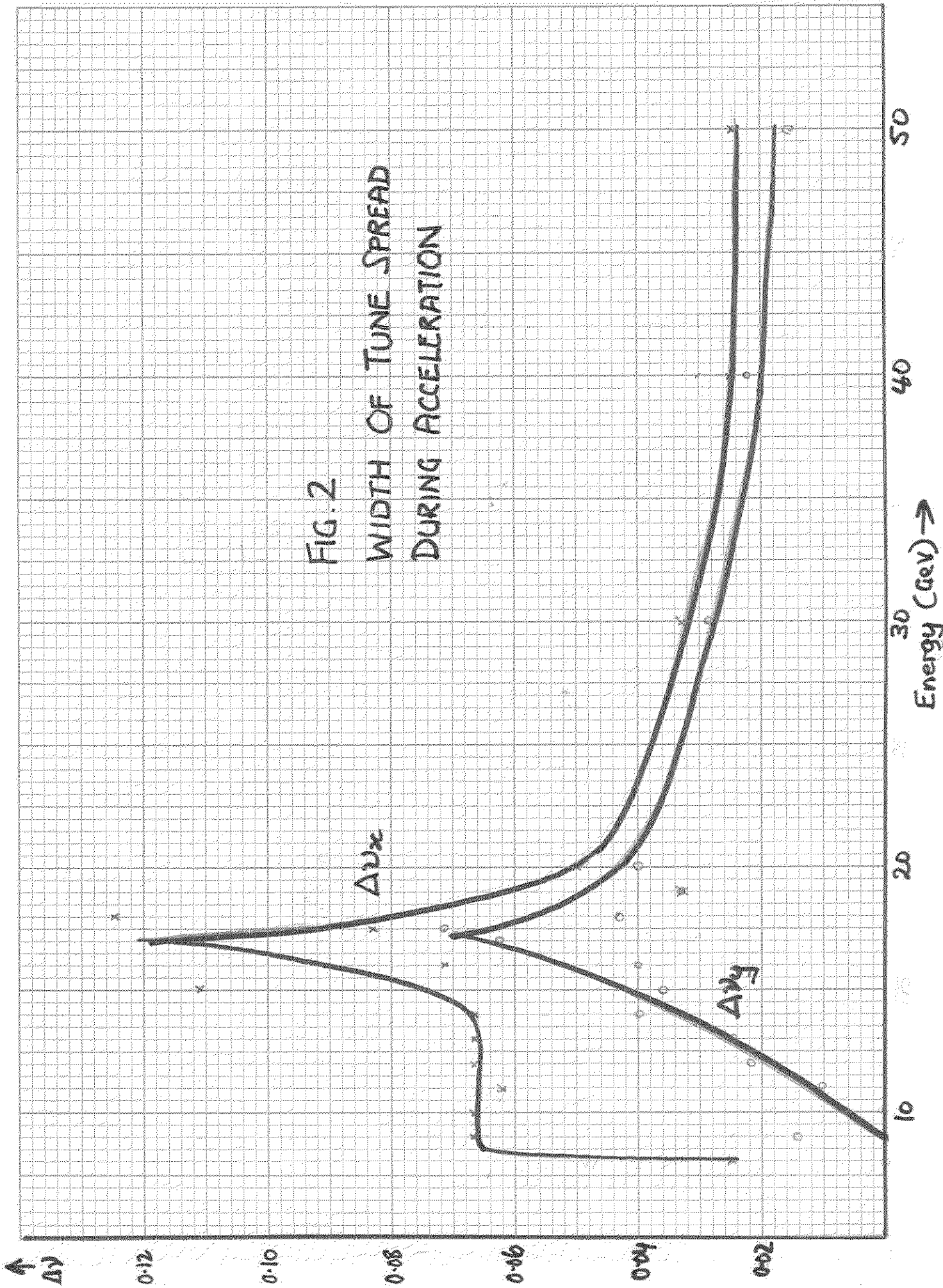
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FIG. 1

Upper trace shows
damped radial position signal
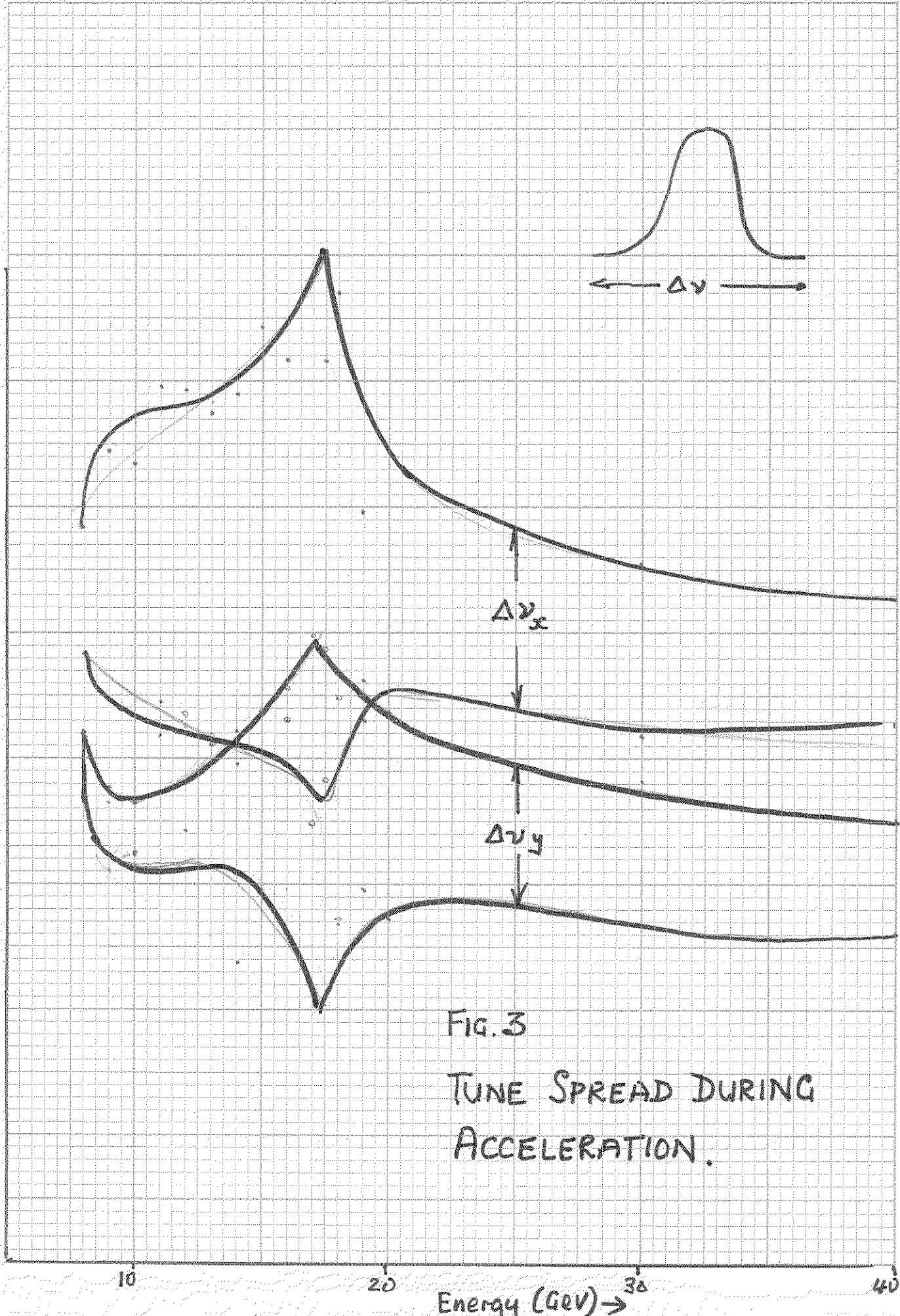after pinging.

(100 μsec/div.)

FIG.2

WIDTH OF TUNE SPREAD
DURING ACCELERATION

Fig. 3

Tune Spread During Acceleration.